Mechanical Issues of Big Cherenkov Detectors

Jenny Thomas

Introduction

- A couple of ideas for large Cherenkov Detectors are emerging for LBNF
  - On Axis at Homestake : THEIA (LS)
  - Off axis at Pactola Lake : CHIPS (water)
- A number of intermediate sized experiments are being planned
- The HK detector is being planned for T2HK
- Many similar developments going on in parallel
  - Good idea to talk about how to make fast progress without everyone reinventing the wheel

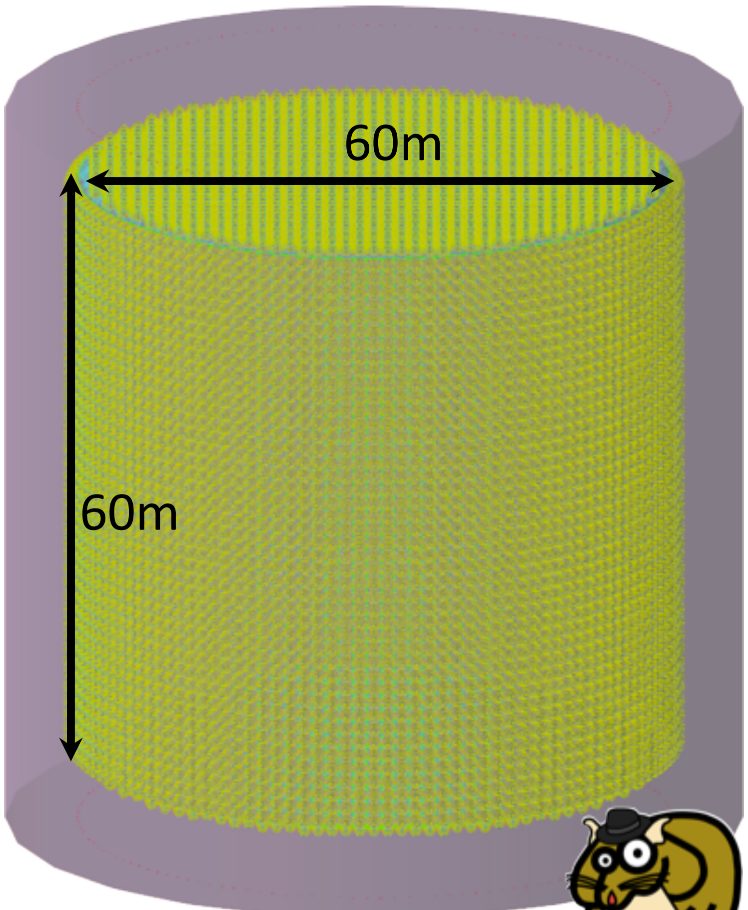
Planned Demonstrations

Site	Scale	Target	Measurements	Timescale
UChicago	bench top	H_2O	fast photodetectors	Exists
CHIPS	50ton	H_2O	readout integration	Exists
CHIPS	10kt volume	H_20	Mechanical infrastructure	2016
EGADS	200 ton	H_2O+Gd	isotope loading, fast photodetectors	Exists
ANNIE	30 ton			2016
WATCHMAN	1 kton			2019
UCLA/MIT	1 ton	LS	fast photodetectors	2015
Penn	30 L	(Wb)LS	light yield, timing, loading	Exists
SNO+	780 ton			2016
LBNL	bench top	WbLS	light yield, timing, cocktail optimization, loading, attenuation, reconstruction	Early 2015
BNL	1 ton			Summer 2015
WATCHMAN-II	1 kton			2020

THEIA:
A realisation of the Advanced Scintillation Detector Concept (ASDC)

- 50-100 kton WbLS target *(M. Yeh talk)*
- High coverage with ultra-fast, high efficiency photon sensors *(M. Wetstein talk)*
- 4800 m.w.e. underground (Homestake)
- Comprehensive low-energy program: solar neutrinos, supernova, DSNB, proton decay, geo-neutrinos, DBD
- In the LBNF beam: long-baseline program complementary to proposed LAr detector

➡ **Broad physics program!**



Detector simulation package under development

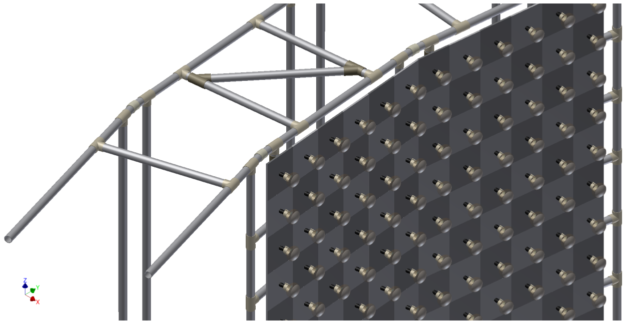
Detector image product of RAT-PAC

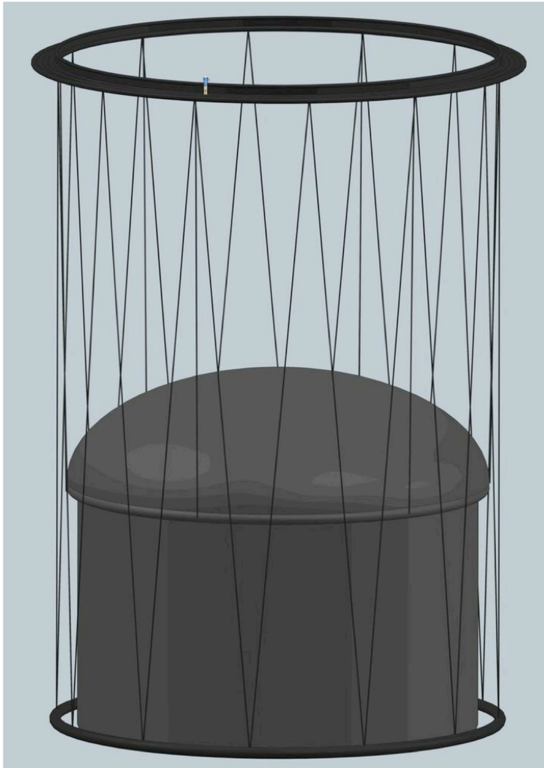
Economy of Scale:
Broad program in a single large detector

- Water-based scintillator target
  - ✳ *High scintillator light yield ⇒ high resolution & efficiency at low E (relative to pure water)*
  - ✳ *Low attenuation ⇒ very large detector*
  - ✳ *Particle ID with direct Cherenkov light ⇒ excellent b.ground rejection*
  - ✳ *Loading with metallic isotopes ⇒ broad physics goals (e.g. DBD)*
- Broad program: a multi-purpose detector with unique physics capabilities
- Flexibility to adapt to new directions as scientific goals evolve in response to new discoveries
- Would utilize the great depth and powerful beam planned for the Long Baseline Neutrino Facility

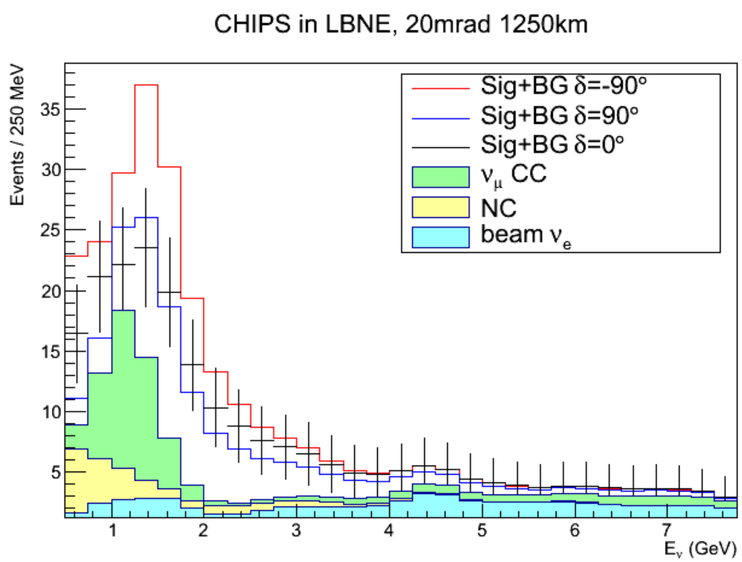
CHIPS Detector Concept

- CHIPS-10 is a water Cherenkov R&D detector sunk in a flooded mine pit in the path of the NuMI beam : water will provide mechanical support
- Will be used as a test bed for developing and testing issues associated with mechanical challenges of moderate underwater pressure
- PSL (Madison) are leading mechanical designs
- Goal is for 100kt in LBNF off-axis, dedicated large, inexpensive beam only detector

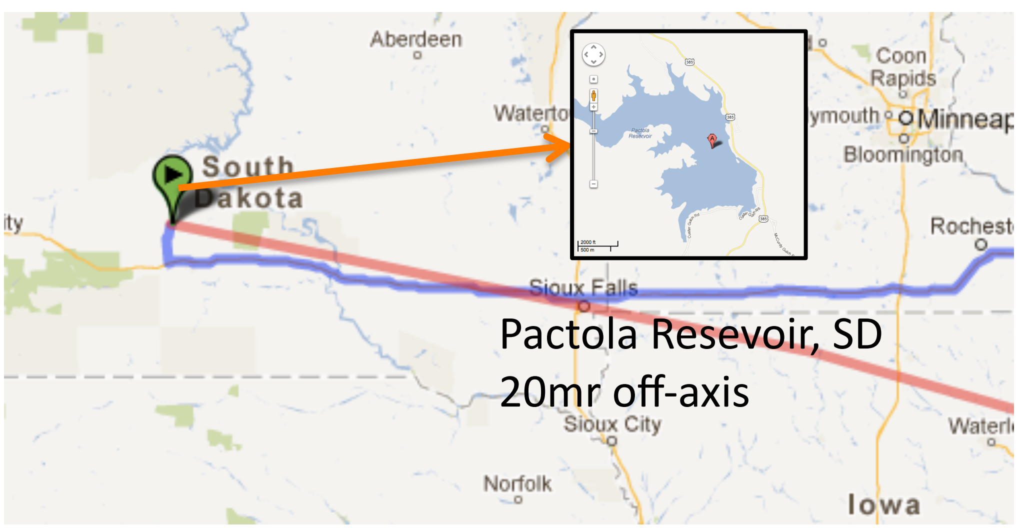


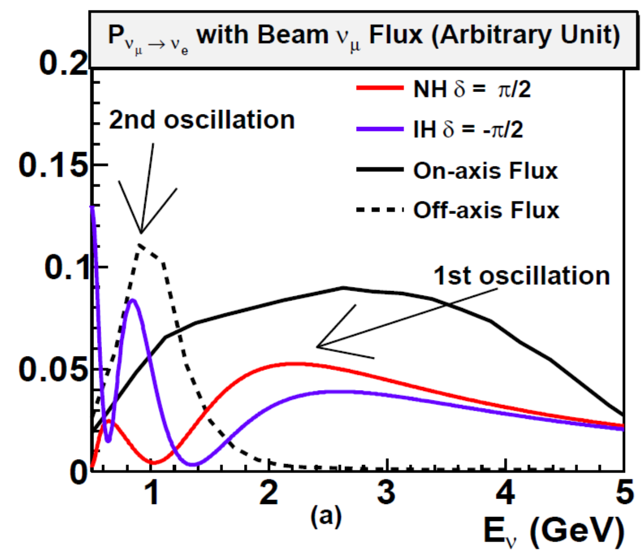


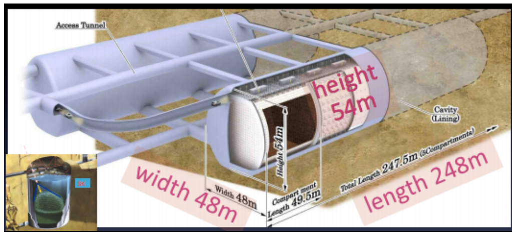
CHIPS@LBNE (20mr off axis)



- 2nd oscillation max around 0.8 GeV
- Large quasi-elastic x-section
- Suitable for water Cerenkov detector
- High efficiency for QE events
- Complementary information to Homestake experiment(s)

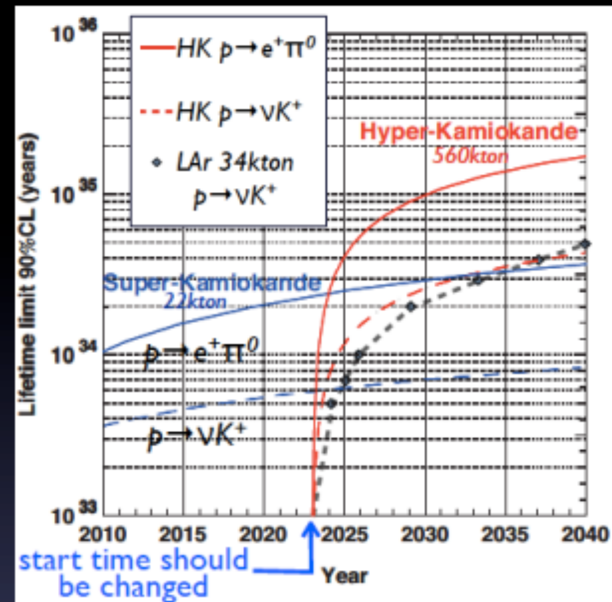


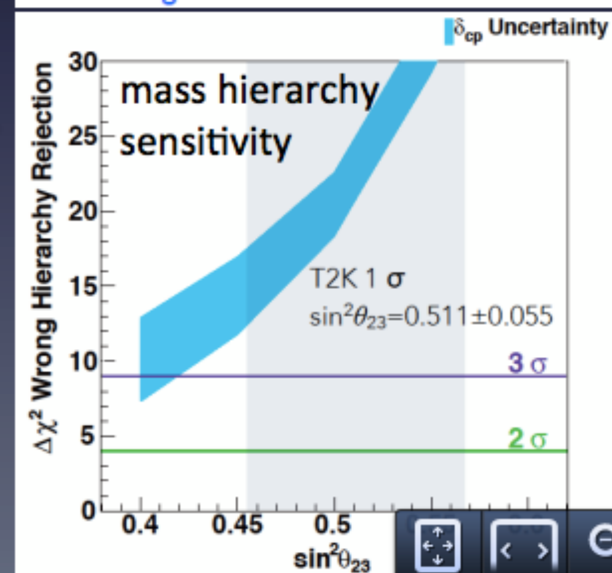




Hyper-K Physics

- **Nucleon decay sensitivity extended by ×10**
  - $p \rightarrow e^+ + \pi^0$: 5.7×10^{34} years (3σ)
  - $p \rightarrow \nu + K^+$: 1.2×10^{34} years (3σ)
- **Search for neutrino CP violation with J-PARC long baseline neutrino beam**
  - 76% coverage of δ_{CP} at 3σ
- **Atmospheric neutrinos**
  - opportunity to resolve mass hierarchy and θ_{23} octant
- **Neutrino astrophysics**
  - 2×10^5 ν events for supernova at GC
  - solar ν, diffuse SN ν, indirect DM, …
- **Geophysics with neutrinos**

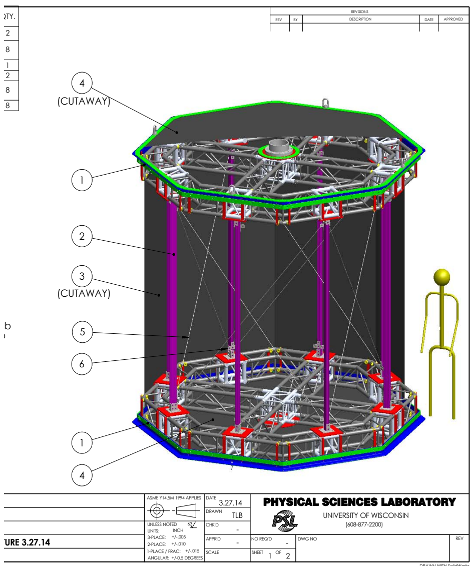


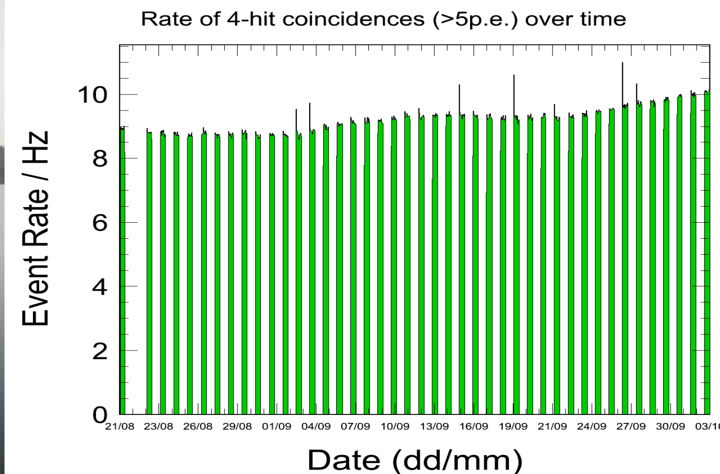


Common Mechanical Issues

- Mechanical Structure and liner
- Development of PMT “module”
  - CHIPS calls for 2500, THEIA for perhaps > 4000
  - One cable per PMT is expensive and bulky
  - Pressure housing for each PMT? Depends on size
    - Lower detectors will face 6 bar pressure
- Development of water tight electronics housings, integrator/event builder
  - Water proof connections are key

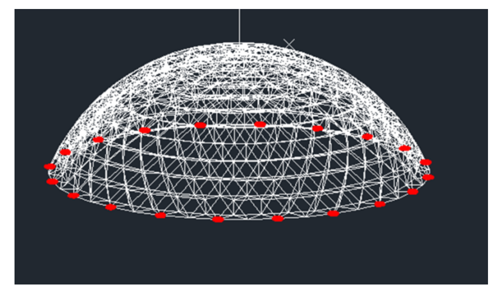
CHIPS-M : submerged test bed

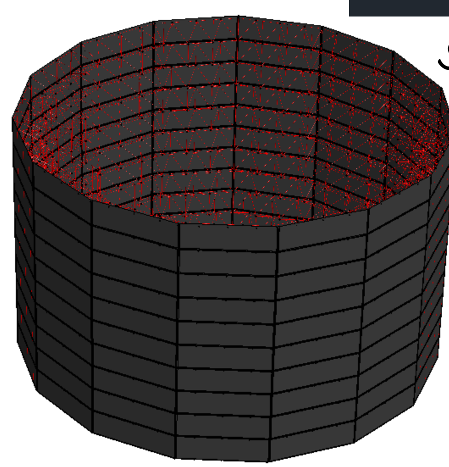




Equipped with IceCube DOMS

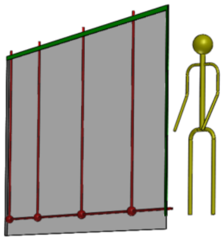
- EIA-KEE-PVC liner (Seaman) : light tight and very strong, also very inexpensive
- Will be raised after 1 year to look for signs of aging in the particular lake water



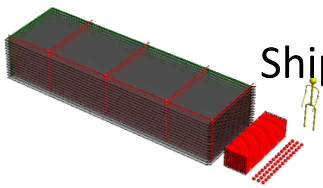


Space frame for 10 kt

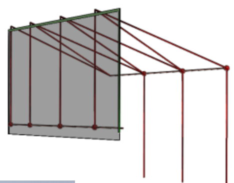
SPACEFRAME and LINER: WALLS



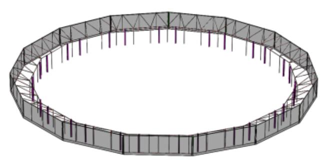
Pre-Fab frame and liner panels



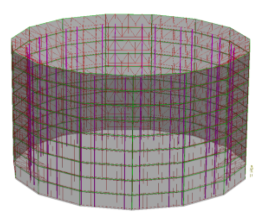
Ship pre-fab panels and hardware



Assemble modules on shore

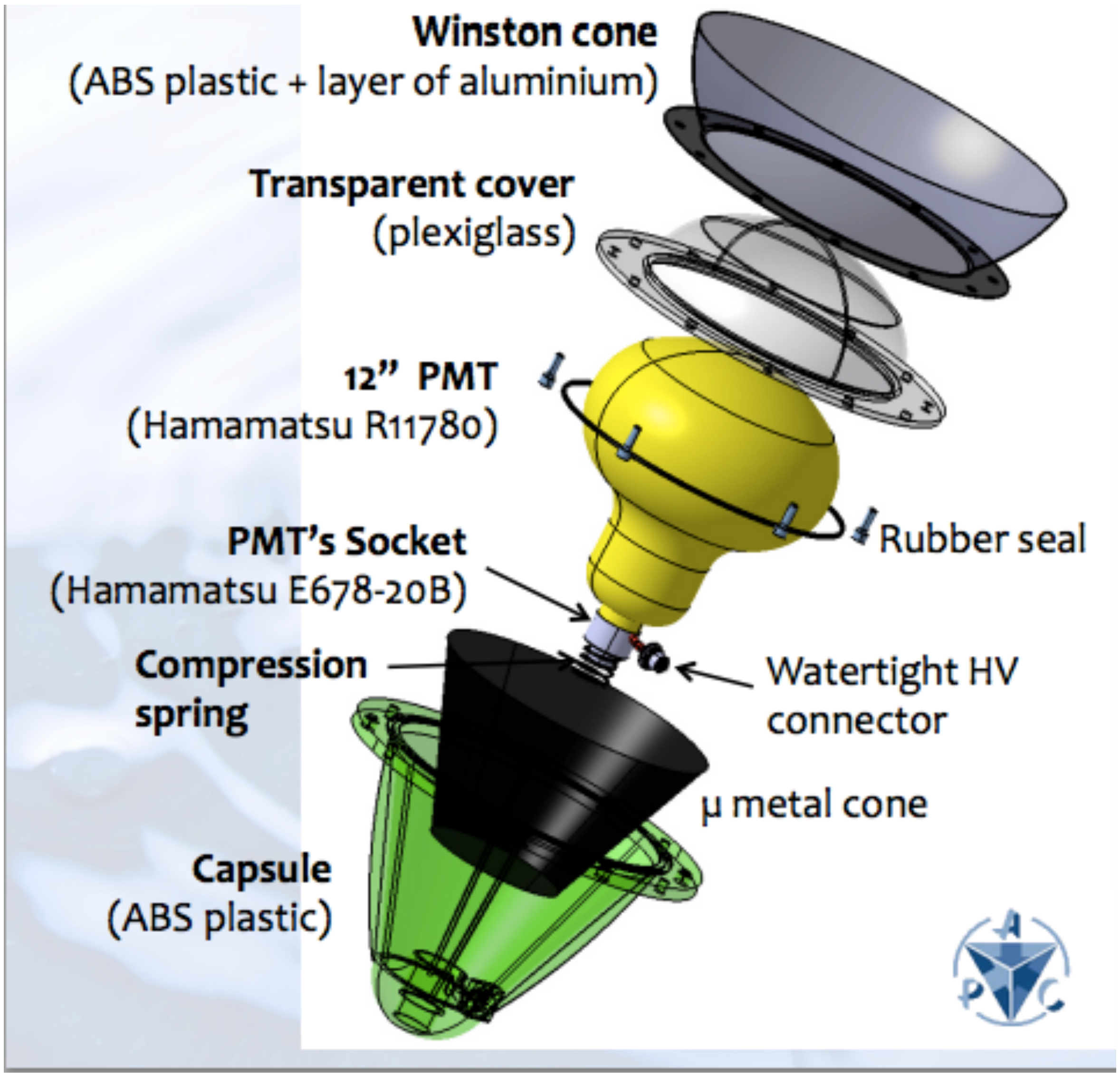


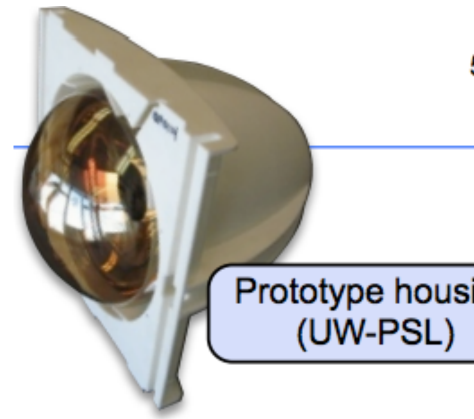
Assemble layers on water



Layer by layer to full detector

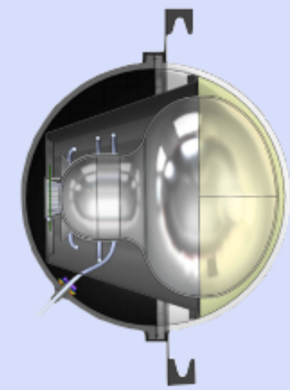
Plastic pressure housing, full or part coverage
Make use of development work that has gone before





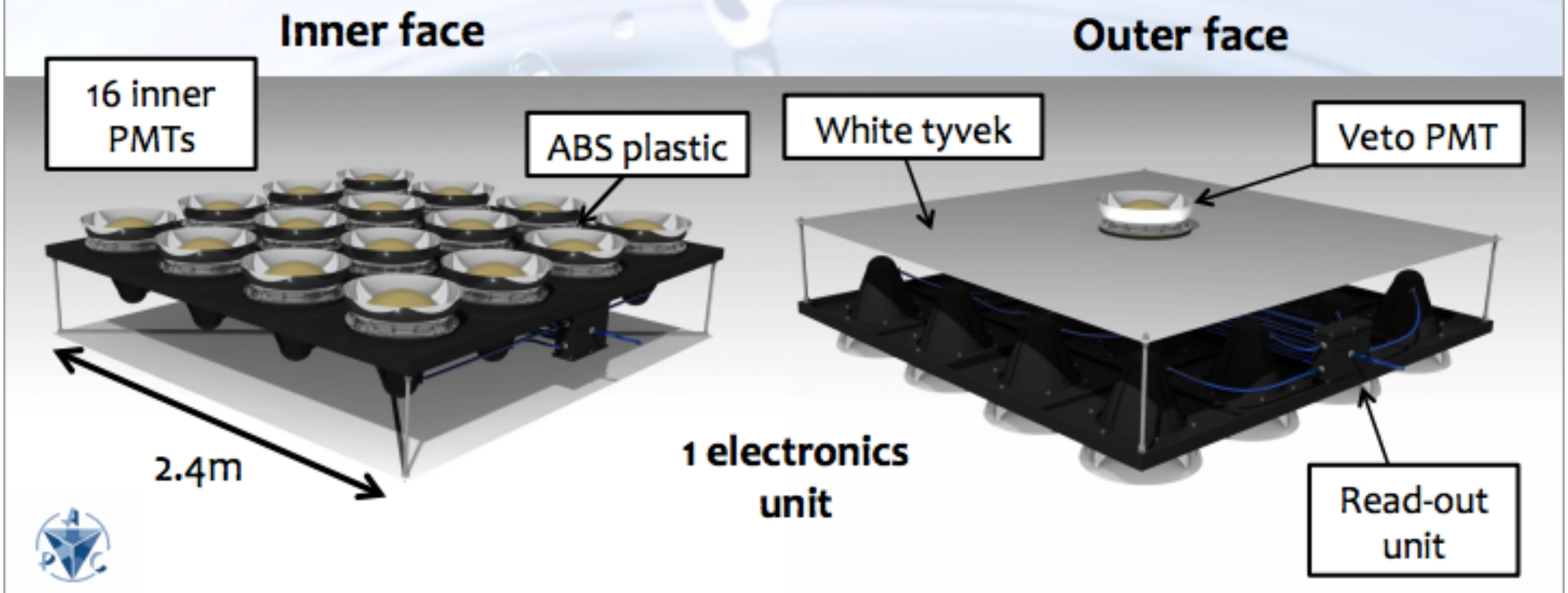
Prototype housing
(UW-PSL)

Pressure housing:
alternate design for LBNE
(D. Wahl, PSL)



- Probably better for deployment in lake

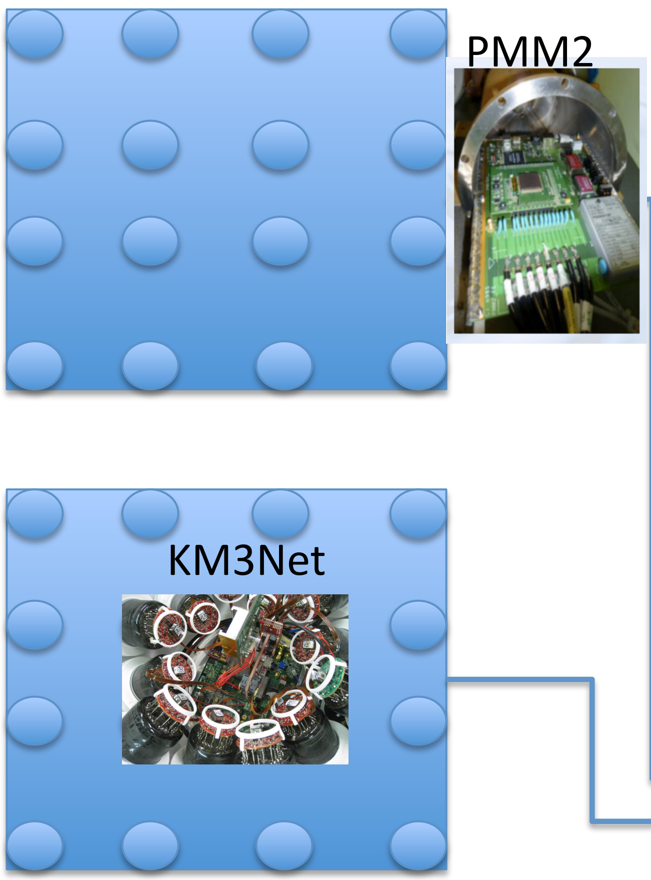
The Matrix: Global Design



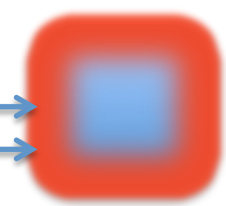
Total Weight ~251 kg

- PMTs grouping
- PMTs support
- Optical Shielding

Additional Integrator

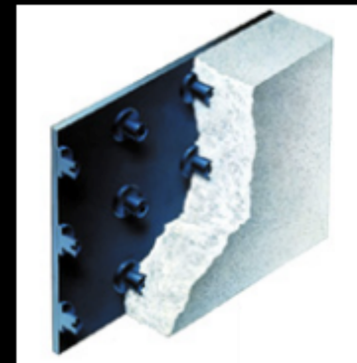


- For THEIA or CHIPS, still many hundreds of panels; again cable cost and bulk an issue
- Intelligence inside to sort and possibly add software trigger
- Underwater connections are a challenge to cost
- But cable length is saved



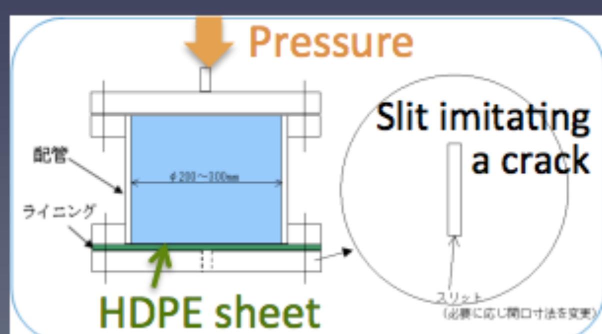
Underwater Event Builder

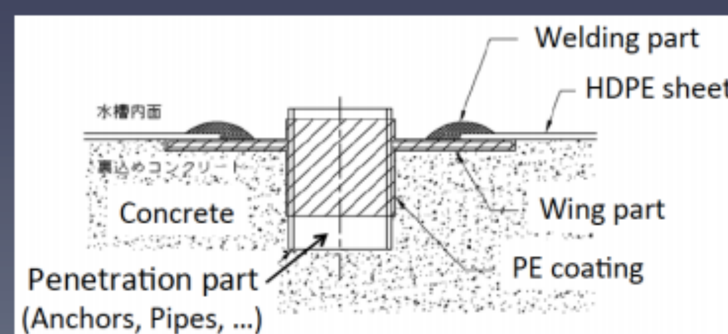
Water Tank Liner



- High Density Polyethylene (HDPE) sheet + Concrete
  - Studs fasten the lining sheet on concrete
  - HDPE liner and concrete layer constructed simultaneously
  - HDPE sheets are welded together
  - Pinholes on lining sheets can be identified by spark tests
- Lining sheet testings
  - Soak tests : in ultra-pure water & in 1%$Gd_2(SO_4)_3$ solution
  - Tensile creep tests, Pressure tests, Penetrating structure tests

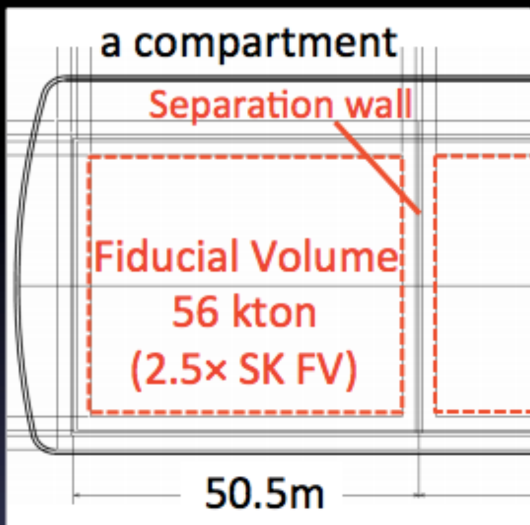
→ Confirmed HDPE liner satisfactory to Hyper-K



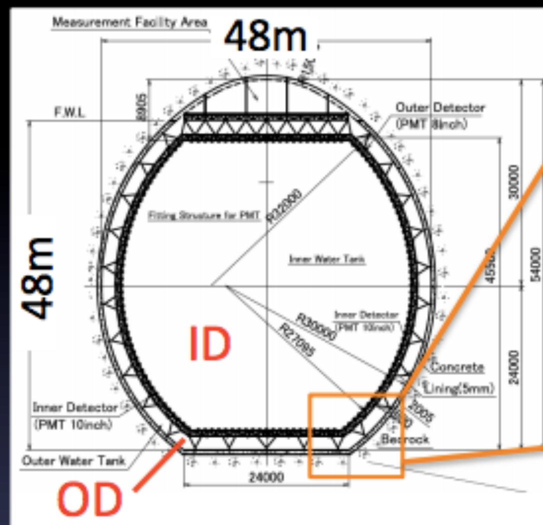


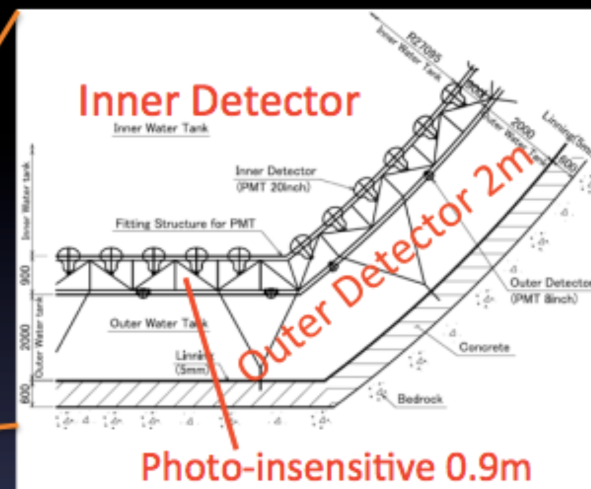
Overall Detector Design

Side view



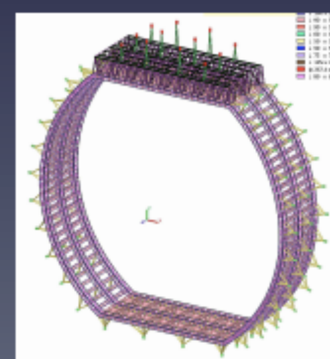
Cross-section

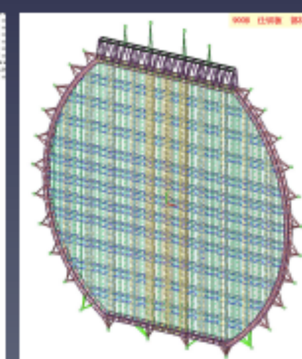




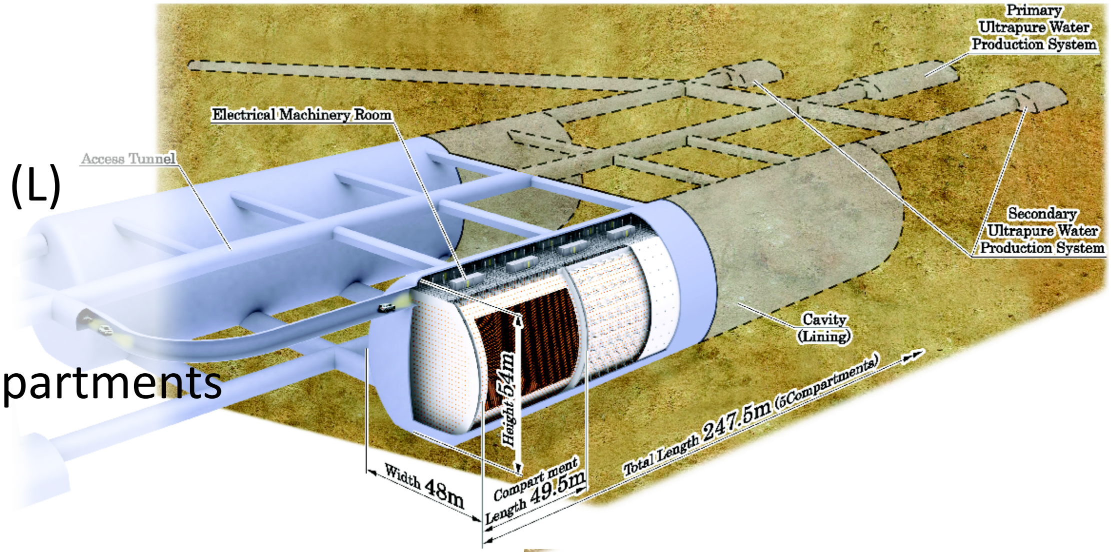
- 2m thick Outer Detector
- Optically separated compartments : 5 × 2
- Water depth : 48m
- SUS304 framework designed for supporting PMTs with covers, cables, HUBs (= underwater elec. boxes), pipes, load on the roof, etc.

SUS304 frames

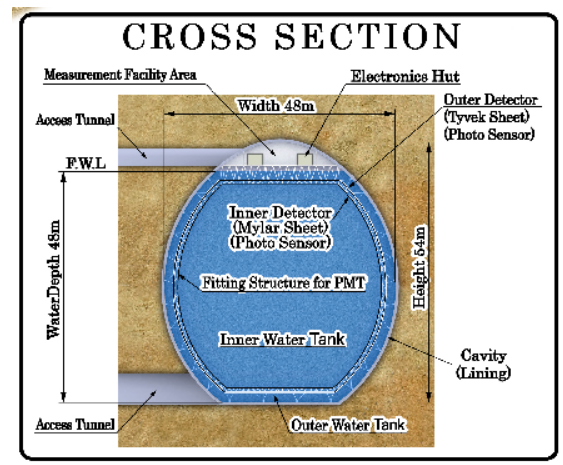




Hyper-Kamiokande Baseline Design



- Two 250m long caverns with egg-shape cross section
  - 48m (W) x 54m (H) x 250m (L) x 2 caverns
  - Water depth: 48m
- Optically independent 10 compartments
- Total excavation volume: ~1.2 Million m^3
- Total fiducial volume: 0.56 Mton
  - FV is defined by 2m from Inner Det. wall
    - 0.9m thick dead region (between ID and OD)
    - 2m thick Outer Detector
    - Number of PMTs = 99,000 50-cm
- Two sites under consideration (Mozumi, near SK) and Tochibora (same OA angle)



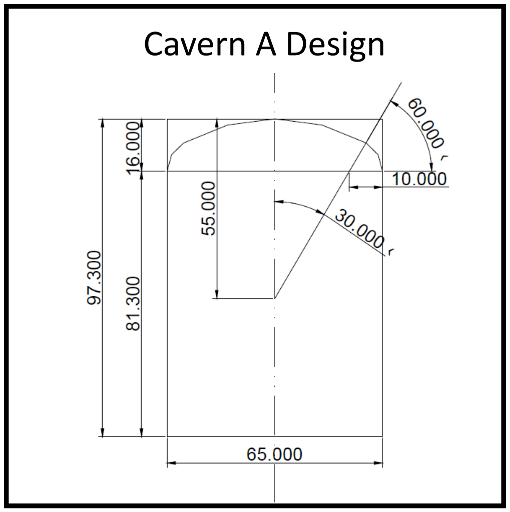
Hyper-Kamiokande Alternate Designs

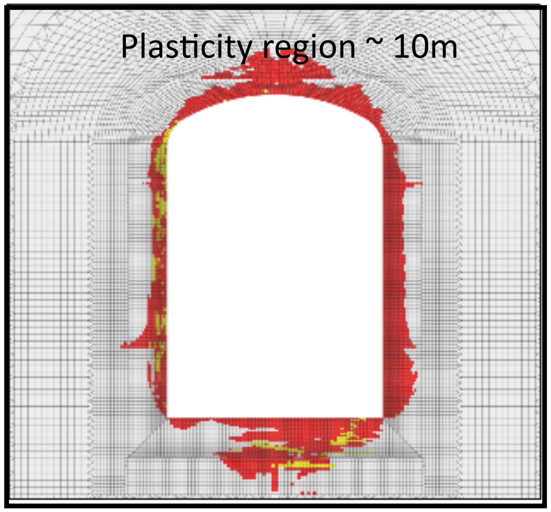
- Although "baseline design" has been defined, alternate designs are under serious study
- Goal: lower the total cost of detector construction
  - Major cost drivers: cavity, tank (structure) and photo-sensor
- Considerations:
  - Simplify cavern shape, ex. vertical straight wall
    ➜ Simplify construction
  - Smaller inner detector surface area
    ➜ Decrease total number of photo-sensors
  - Reduce excavation volume while keeping fiducial mass
    e.g. thinner veto detector layer

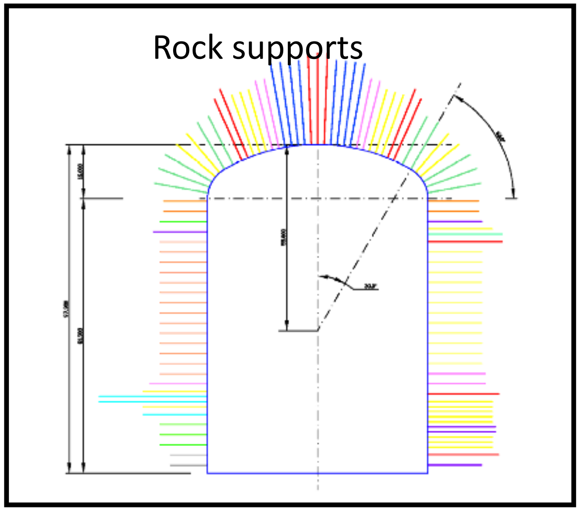
    ➜ Reduce the excavation cost

e.g. Hyper-K Alternate Cavern A

- Cavern dimensions: 97m height x 65m diameter, 80m water depth
- H/D ratio of 1.5 gives smaller (better) plasticity region depth – fewer rock anchors
- Straight wall cavern simplifies construction and mounting of photo-sensors
- Requires higher pressure tolerance, maybe smaller PMTs than 50-cm
- Alternate Cavern B: 76m x 76m with 60m water depth also being studied

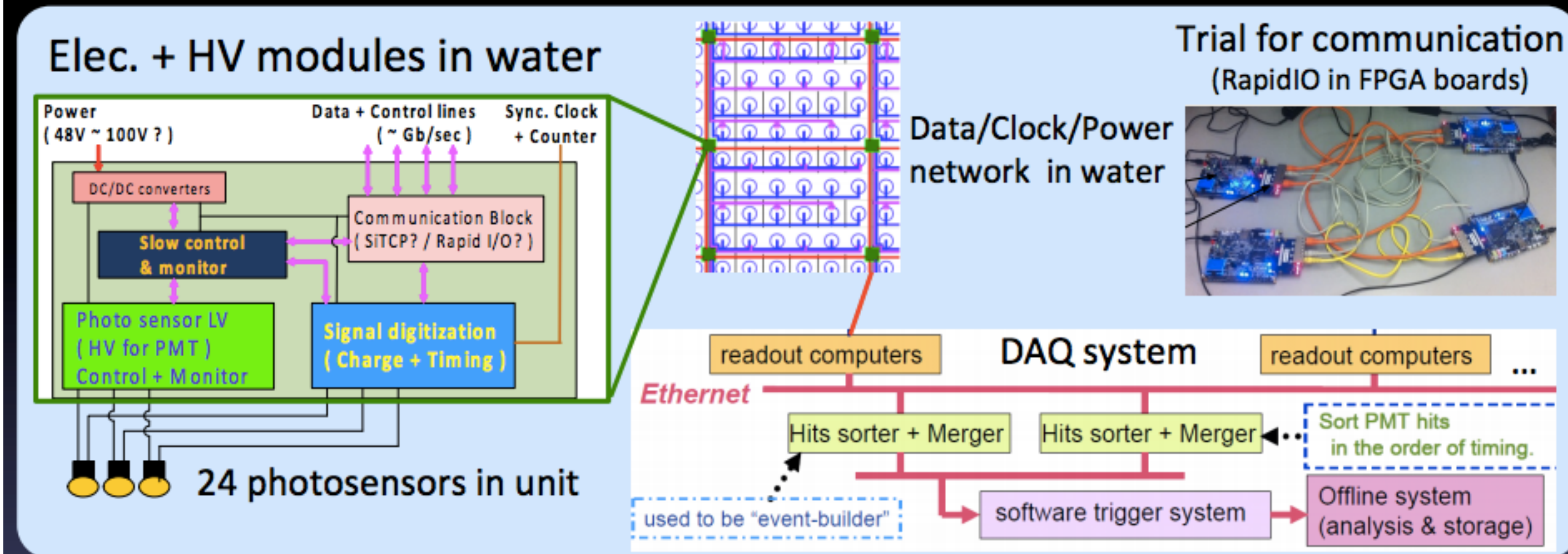






Excavation and tank construction procedure design and cost estimates are underway. Multiple companies involved.

Electronics and DAQ



- Planning to put photosensor power-supplies & electronics in water
- Investigating a few options for front-end elec. (QTC+TDC / FADC)
- DAQ system also being designed
  - nominal starting point : current Super-K DAQ
    → digitizing all signals (T&Q) + defining events with software
- To be tested with the WČ prototype detector

Solution-mined salt caverns for future detectors

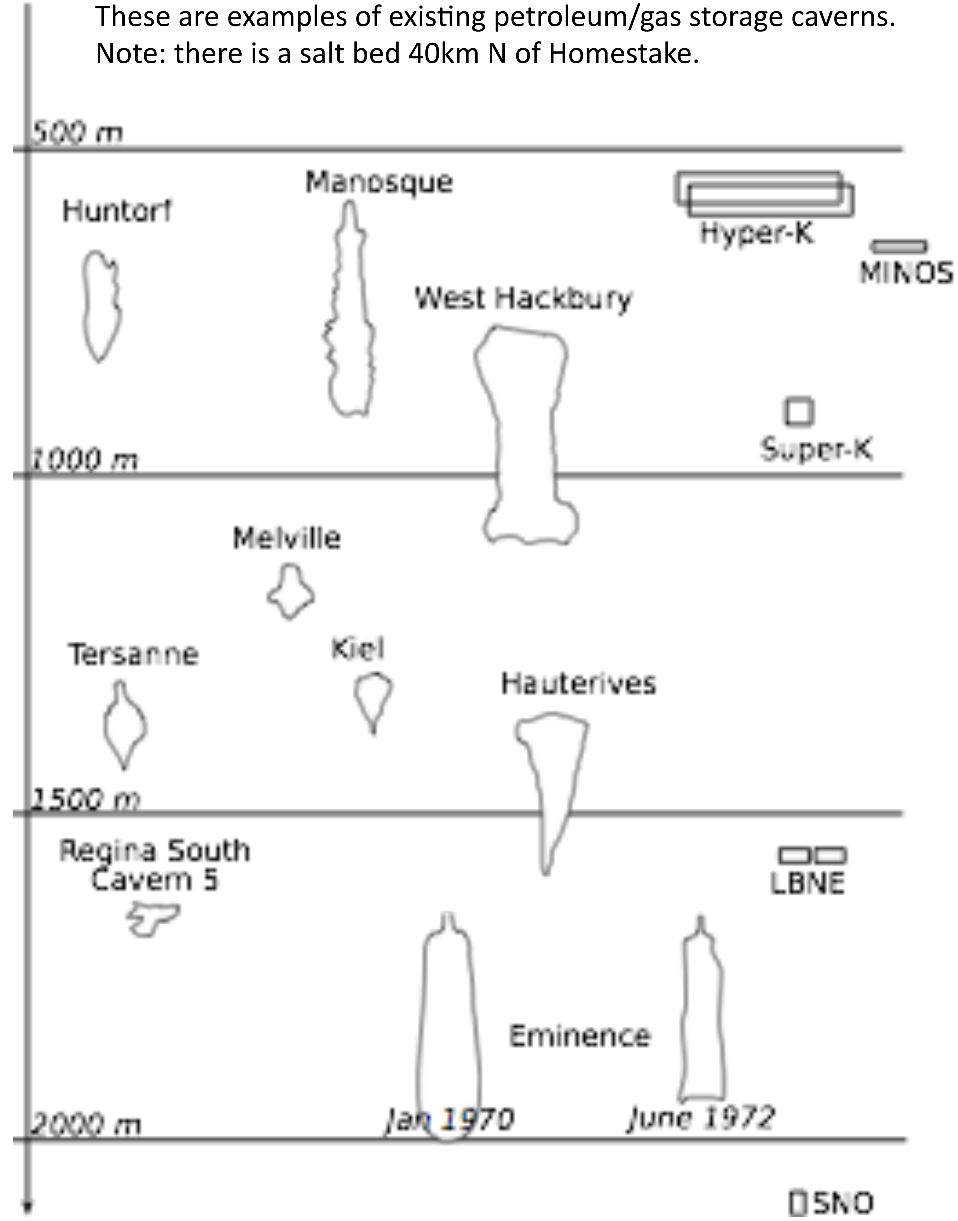
Ben Monreal, UCSB
see arxiv:1410.0076

- Giant caverns are "mined" by piping fresh water into a salt dome or bed
- Very very cheap: \$2/m^3 ?
- Trick #1: No miners! Crane/robot access only. Install detector via vertical drill shaft, like a ship in a bottle. (Not as hard as it sounds.)
- Trick #2: if deeper than ~1km, cavern needs internal pressure (100+ bar) to hold off salt creep

Two ideas:
- use cavern as pressure vessel for multi-kt gas TPC (CH_4, Ar, Xe)
- multi-MT water Cerenkov using IceCube DOMs

Some design study has been funded. Seeking collaborators!

These are examples of existing petroleum/gas storage caverns.
Note: there is a salt bed 40km N of Homestake.



Summary

- There is significant activity in the general area of Cherenkov detectors
- Many issues are common, from mechanical structure to PMT modules to electronics
- It would be great to get organised to raise awareness and likelihood of R&D funds to work together on these issues